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Photovoltaics in Mexico: A Model for Increasing the Use of Renewable Energy Systems

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Introduction

Every year during the hot, dry spring months, Marcos Alvarez, a cattle rancher in the desert of Baja California Sur, Mexico, faced a situation that cost him many thousands of pesos and the loss of some of his herd. During this time, he would have to buy expensive feed for his 39 steers, and his ranch hands would spend extra hours each day ensuring the cattle had sufficient water. Now, however, he has new grass coming up in the spring, water flowing automatically into troughs, and an emergency supply of food for his cattle in the form of silage produced from grass grown on his ranch (Burroughs 1998).

Figure 1. A photovoltaic water pumping system at Colonia Modelo, Chihuahua has improved overall ranch profitability since it was installed in March 1997. After that time, three other photovoltaic water pumping systems have been installed in the area.

Meanwhile, Mauricia Gonzalez, an engineer with Línea Bíosfera, a non-government organization working in Mexico's El Ocote Ecological Reserve in Chiapas in southern Mexico, struggled with the logistics and expense of coordinating development, conservation, and emergency-response activities in the remote and isolated villages typical of the Reserve. Now, a new radio communications system, improved training facilities, and a water-pumping system have greatly enhanced the operation and effectiveness of Línea Bíosfera, cutting operational expenses and bringing much-needed services to the poverty-stricken people with whom the engineer and the organization works(Romero, Büttner 1997; González 1998).

Figure 2: Thanks to a photovoltaic system, Mauricia Gonzalez and the other staff of Línea Bíosfera now use the time they used to spend hauling water on advancing their development and conservation work.

In both cases, installing solar photovoltaic systems provided immediate and economic solutions to vexing and costly problems, in agriculture in one case, and in environmental conservation and development in the other. Use of these systems began as an experimental project and has subsequently become a trend, in which U.S. and Mexican businesses are partnering to establish a supply and service infrastructure in response to a growing commercial market. Furthermore, this trend of increasing commercial use of renewable energy technologies in lieu of traditional fossil-fuel-based approaches is part of a solution to the world-wide concern of offsetting greenhouse gas emissions.

These three objectives--enhancing economic and social development, creating new business opportunities, and offsetting greenhouse gas emissions--are the essential goals of the Mexico Renewable Energy Program, which is managed by Sandia National Laboratories for the United States Agency for International Development (USAID) and the United States Department of Energy (USDOE).

Background of the Renewable Energy Program in Mexico

Sandia's work in Mexico began in the early 1990s as part of work sponsored by the U.S. Department of Energy's (USDOE) National Photovoltaics Program and by the Committee on Renewable Energy Commerce and Trade (CORECT). Initial efforts were aimed at expanding the market for U.S. renewable energy technologies in Mexico, primarily for photovoltaics, but with some emphasis on small wind-energy systems. The program was designed to address potential markets and applications that were not already being addressed through other programs, such as those sponsored by the Mexican federal government (Huacuz, Agredano 1998). Various efforts were undertaken to develop specific renewable energy projects and to develop relationships with key organizations in Mexico (Rovero 1992). In late 1992, the Mexico office of the U.S. Agency for International Development (USAID) joined the on-going project in support of its objectives to promote environmentally sound economic and social development in Mexico.

Goals of the Program

The program supports objectives of both USDOE and USAID. The Department of Energy is interested in building a strong renewable energy industry in the United States as part of its responsibility to ensure national energy security through diversity of energy supplies. Mexico presents an attractive market for the U.S. renewable energy industry (Hanley *et al.* 1998) because more than 5 million Mexicans in 88,000 villages do not have access to grid-supplied electricity, and more than 100,000 rural communities need potable water. In addition, at least 600,000 ranches need water for livestock and/or irrigation. If these requirements were supplied by renewable energy systems where appropriate, these markets alone would total more than a billion dollars (Barnett, DiGregorio 1998). Mexico's proximity to the United States and tariff benefits provided by the North American Free Trade Agreement facilitate importing U.S.-produced renewable energy products into Mexico and establishing relationships among U.S. and Mexican businesses.

USAID's primary mission is social and economic development in the countries where it works, but it also supports U.S. business interests where appropriate, especially where such support facilitates development. Energy supply and economic development have been shown to be closely linked (U.S. Congress 1991; U.S. Congress 1992; Hankins 1993). In rural economies where no electricity supply grid exists and the population is relatively dispersed, access to even small amounts of electricity can have a large effect on a community's capacity for economic development (Orozco 1990; Villagran and Orozco 1992). Renewable energy technologies are often technically and economically the best options in these situations because they are small, distributed, modular, and low-maintenance.

Both the USDOE and USAID are also interested in environmental issues. Of particular concern is the dramatic increase of carbon dioxide and other greenhouse gases in the atmosphere, which is widely believed to be a primary cause of global climate change (Foster 1998; World Bank 1997; Dunn, Flavin 1998; O'Meara, Flavin 1998). Energy use, including all aspects of power production, is the largest contributor to these emissions, because the carbon in fossil fuels is released as it is burned. It is predicted that continued unrestricted burning of fossil fuels to meet growing global energy needs would double carbon dioxide levels in the atmosphere in the next century, producing drastic consequences for the planet from the resultant global climate change. Because renewable energy technologies generally release very small net amounts of carbon or other emissions as they produce power, they are widely regarded as part of the solution to the problem of global climate change (National Laboratory Directors 1997). However, the practicalities involved in actually deploying renewable energy technologies toward this objective are considerable, and they relate closely to the other goals of the Mexico Renewable Energy Program.

Focus of the Program

The Mexico Renewable Energy Program unites the goals of promoting use of renewable energy systems and of enhancing economic and social development, creating new business opportunities, and offsetting greenhouse gas emissions. These goals are broad, and for this reason, the program has had to target specific sectors in which to work to be successful. The original concept was, and still is, focused on rural, off-grid, productive-use applications of renewable energy, particularly photovoltaics and small wind, with some interest in small hydropower and solar thermal systems. Rural off-grid applications are currently the most cost-effective and economical for small renewable energy systems. Productive-use applications are those that provide an economic or social benefit to the user of the technology, such as water pumping for agricultural use or lighting for an ecotourism facility. Because of the income they provide, productive-use applications provide a built-in means for paying for a renewable energy system and can compete successfully in markets that are influenced by subsidies, such as those provided by the Mexican government for solar home lighting systems.

Within the context of rural, off-grid, productive-use, two primary sectors emerged as the most promising, at least in the near term. One is Mexico's agriculture sector, which is implementing large and varied activities in support of agricultural development across the country. In particular, photovoltaic water pumping emerged as a main focus of the work, providing an opportunity to aggregate a market and provide the critical mass needed to establish and sustain local renewable energy business. The other primary sector on which the program has been focused is protected-areas management, which combines the preservation of critical and endangered ecosystems with environmentally sensitive development in the communities in and surrounding protected areas. USAID/Mexico is active in this arena and strongly encouraged the linking of the renewable energy program with the protected-areas management (PAM) programs in Mexico. Although the productive-use benefits of the PAM projects are sometimes difficult to quantify in traditional economic terms, the uncertainty in the economics is outweighed by the assumed large conservation or environmental value inherent in the projects, the long-term benefits and synergies of learning how to integrate renewable energy into protected-areas management, and the possibilities for replication in other countries via the PAM partner organizations.

Other activities under the program include work with small wind power systems, a hybrid village power system, and solar water distillation. Projects involving applications for solar thermal systems have also recently gotten underway, and it is possible that small hydropower systems will be undertaken in the future. However, the focus of this paper is primarily photovoltaics, the technology that represents most of the work under the program to date.

The Program Model

Many of the principles on which the Mexico Renewable Energy Program are based stem from Sandia's experience with the Photovoltaic Systems Assistance Center (PVSAC) (Stevens *et al.*, 1986). For more than 10 years, Sandia's PVSAC has been working with a wide variety of organizations and individuals to increase the use of photovoltaics and, as a result, has established some reliable guidelines to help ensure the success of photovoltaic projects and increase the likelihood that sustainable markets are developed. The philosophies of Sandia's PVSAC are inherently practical, beginning first with advice not to start programs from scratch if possible. That is, build on existing capabilities by partnering with established organizations and work within established and funded programs. It is also advisable to work with a champion for the project, someone within a partner organization who takes on the program or project as a personal cause. Then provide technical assistance, training, and hands-on experience to build within the partner organizations the institutional capacity to make use of renewable energy technologies. Second, one-of-a-kind applications should be avoided and only proven commercially available hardware used to ensure a high degree of replicability for the project. Third, it is important to focus program activities and resources on the most promising partners, applications, technologies, geographic areas so that a critical mass of business activity can be established and maintained around a given market. Once the level of business activity in a particular application and location can sustain itself, new applications or locations can be tried more easily by building on the infrastructure thus established.

The model for the Mexico Renewable Energy Program combines the general guidelines from the PVSAC with the experience of working in Mexico for the last five or so years. Its fundamental aspects are:

- Partnerships
- Capacity Building
- Technical Assistance
- Implementation of Pilot Projects
- Replication, and
- Monitoring.

Partnerships

Partnerships, especially with in-country organizations and individuals, are critical to progress and success in an undertaking such as the Mexico Renewable Energy Program. It would be unrealistic to think that a U.S.-based organization could accomplish anything significant and long-lasting in another country without working closely with local organizations. Furthermore, because mixing technology with the diverse issues of social and economic development, environment, and business results in a very complex situation, it is unlikely that any one organization will have all the needed expertise.

The Sandia program partners with well-established project-implementing organizations in Mexico, including federal, state, and local government agencies and international and local non-government organizations, and works to incorporate the use of renewable energy into their ongoing development programs. The program also works closely with U.S. and Mexican businesses, as well as with Mexico's Solar Energy Association (*Asociación Nacional de Energía Solar* [ANES]). These partnerships have been key to the success of the program. Ultimately, the intent is for management and implementation of the program to be transferred to one or more of the partnering country's institutions.

The diverse nature of the objectives and activities in the program requires a diverse set of competencies in the implementation team. Therefore, partnering among a variety of organizations and individuals from both the U.S. and Mexico is also essential in assembling the program team. So, in addition to the approximately 25 contracts that have been placed with partner organizations in Mexico for specific project activities, Sandia's core program implementation team involves about 30 people either from Sandia or from one of eight or so organizations under contract with Sandia.[1]

Maintaining trust and cooperation among the partners in such a complex partnering arrangement is critical to success because the integration of various issues associated with energy, technology, development, and the environment into a coherent set of activities would be impossible without it.

Capacity-Building

Building in-country institutional and/or community capacity to deploy, use, and maintain renewable energy technologies is another fundamental requirement for program success. The failure of many technology projects around the world can be blamed on neglecting to address this issue. Capacity-building takes different forms and involves different disciplines depending on the situation. Targeted training workshops and seminars are effective and efficient means of reaching relatively large numbers of people and organizations. Formal training alone, though, is usually insufficient, so it must be tied to ongoing projects where hands-on experience can be gained and more focused individual assistance can be provided as needed. The implementation

[1] Please see the acknowledgments for the diverse set of contributors to this work.

of pilot projects has proven to be an outstanding way to build capacity, as discussed in more detail below.

Capacity-building needs vary depending on the role of the organization or individual in a project. Project-implementing organizations, such as government agencies or non-profit groups, need to know how to define needs for energy service, evaluate options for meeting the needs (including the economics), develop and prepare specifications to procure systems, evaluate and select bids, conduct acceptance testing, and inspect and monitor installed systems. Users may need to deal with any or all of these tasks, and also with how to operate, maintain, and obtain service for the system. Local suppliers of renewable energy technologies need to know how to size and design a system properly, prepare bids that meet specifications, install systems properly and assure their proper and safe operation, handle warranties and maintenance, and partner with equipment distributors and/or manufacturers. Financial institutions need to know how to evaluate the viability of projects, the life-cycle costs, and the payback times, and what the inherent risks are. And sometimes, U.S. industry may need a little capacity-building of its own in order to do business internationally.

Technical Assistance

Technical assistance contributes to, but is different from, capacity building. It involves ensuring that projects are technically, economically, and environmentally sound, and it provides information or expertise that may not be available in-country, such as resource assessment data. If carried out in partnership with capacity building, the need for technical assistance with any one group, organization, or individual, will generally diminish over time.

Although the program is limited to using proven, commercially available hardware, and specific system design is the responsibility of the suppliers, a considerable amount of technical analysis is still required to ensure successful projects. Potential project sites and their associated energy needs must be analyzed to see if they are suitable for renewable energy systems, available renewable energy resources must be assessed, the appropriate technology must be selected, system specifications must be prepared and enforced, bids must be analyzed, installations must be done properly, acceptance testing must be performed, and systems must be properly maintained. Economic and financial analyses are also necessary, as is environmental impact assessment.

The program team does not take all this on themselves, but rather works with the in-country partner organizations to ensure that these things are handled properly. In addition to ensuring that renewable energy systems installed under the program are sound, the Mexico program team has given particular attention to providing assistance with assessing the solar and wind resources. Experts from the National Renewable Energy Laboratory analyzed available weather and resource data from in-country sources and satellite information, in combination with new resource information collected from data acquisition systems set up through the program, to develop solar and wind resource maps for the country as a whole in the case of solar, and for individual areas of interest in the case of wind, as shown in Figure 3. The program team also worked with the in-country partners to develop and incorporate a process for ensuring the environmental impacts of projects were properly addressed. As the partner organizations increase their experience through a few rounds of pilot-project implementation, they need less and less assistance and eventually are able to handle everything themselves.

Implementation of Pilot Projects

A key feature of the Mexico Renewable Energy Program is that it uses pilot projects to institutionalize the use of renewable energy. As mentioned before, hands-on experience is a necessary ingredient in capacity building. Pilot projects provide that opportunity, as well as serve to publicize, promote, and establish the credibility of the technology. They are fundamentally different from traditional demonstration projects in that they are generally commercially replicable and, with few exceptions, are actually *implemented by the partner organizations* rather than by the program team. The current program in Mexico implements three basic types of pilot projects: fast-track training projects (for example as shown in Figure 4), cost-shared projects, and non-cost-shared projects.

Fast-track training projects install systems early in a partnership as part of a formal training workshop to jump-start capacity-building, generate enthusiasm for the program, and establish the credibility of the technology in a particular area and/or with a particular partner. In these cases, the program provides the renewable energy hardware including installation by industry, while the partner organization generally covers logistical costs and the beneficiaries provide in-kind support for balance-of-system components, such as water tanks, distribution systems, fencing, etc.

In cost-shared pilot projects, the Sandia program provides funding to share the cost of pilot system installations implemented by in-country partner organizations. The intent is to buy down the costs of doing something for the first time. While the partner organization is coming up the learning curve on renewable energy projects, the overhead costs are larger than for the more familiar traditional options. Having some funds to help offset these extra costs is helpful in getting the process going. This facilitates a key feature of the Mexico program model, which is that partner organizations become involved in system procurement early in the program, rather than depending on the program team to supply hardware. This can slow pilot projects down and cost a bit more, but it is an essential step in the capacity-building process. It should be noted that, because this program is federally funded, the program model needs to account for the logistics of moving U.S. government funds into another country for the purchase of hardware, not a trivial matter if the proper contracting mechanisms are not set up. The Mexico Renewable Energy program, in partnership with USDOE, USAID, and the Mexican partner organizations, set up a contracting mechanism that served both requirements for programmatic and fiscal accountability. More information on this is given in the section on lessons learned.

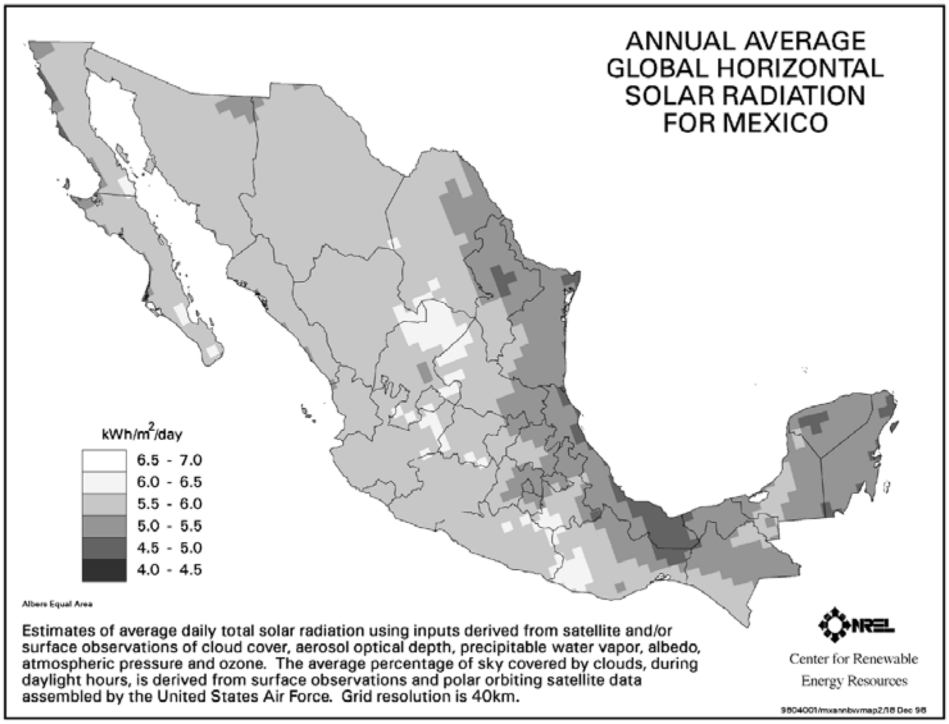

Figure 3. Map developed by the National Renewable Energy Laboratory showing average daily solar radiation in Mexico.

Non-cost-shared pilot projects are implemented by the partner organizations with technical assistance and capacity building from a technical program, such as Sandia's, but with no funds provided for cost-sharing the hardware. As a program progresses and the word spreads about the success of systems installed so far, having funds to cost-share pilot projects becomes less critical to the success of the program.

Typically the Sandia program will work with a specific partner organization through two or three rounds of pilot project implementations, each with a diminishing percentage of hardware cost share (where cost sharing is used). At the beginning, considerable assistance and training for the implementation organization, the local suppliers, and the users is needed, but once the partner has been through the process a couple of times, very little assistance is needed from the program team. At that point, the program enters the project replication phase, which is described below.

Figure 4. Training activities are tied into the implementation of pilot-projects, such as this photovoltaic water-pumping system installation in Buena Vista for the Chihuahuan Renewable Energy Working Group.

Project Replication

Project replication, or growing sustainable markets, is the program's ultimate measure of success or failure. For example, the budget over the six-year life of the USAID/USDOE Mexico Renewable Energy Program to date is approximately $10M, an amount that could have bought a much larger quantity of renewable energy product than has been installed to date. However, the program is about avoiding the results that would be produced by doing that: significant short-term sales but few or no follow-on sales, followed by widespread system failures, leading to a furthering of the negative reputation of renewable energy systems. By investing most of the program cost into in-country capacity building within the partner organizations, the user community, and the suppliers and maintainers, it is expected that sustainable markets many times larger than the cost of the program itself will be realized through replication.

Project replication takes place in a number of ways. As successful pilot projects are implemented and internal capacity to implement renewable energy projects is established, institutions begin to implement other projects on their own in accordance with their programmatic objectives, say, agricultural infrastructure improvement in the case of Mexico's agricultural development agency. This generally takes place first at the local level, such as within a state office of this agency, then spreads to other regions as one state office works with another state office. In the case of the protected-areas management sector, replication can occur from one reserve to another or one country to another as the use of renewable energy becomes recognized as a good means to accomplish organizational objectives. The potential for project replication within an institution such as a development organization can be huge, given that overall development project implementation budgets can be in the millions, even billions of dollars. Replication can also occur from one institution to another.

Private-sector spin-off replication occurs as a result of successful pilot projects implemented in a particular area. Necessary ingredients for this type of replication are a recognized need for the services the technology can provide, a local awareness of the technology, credibility of the technology in meeting the need reliably and economically, local availability of quality products and services (i.e., local renewable energy businesses), and the ability to pay for the technology.

The availability of financing can greatly affect the pace of replication. Even when renewable energy technologies are the most economical choice on a life-cycle-cost basis, their relatively high initial capital costs often require access to financing in order for markets to expand. Accordingly, facilitating financing mechanisms, both for projects implemented in the course of large development programs and for private-sector sales, is a key part of project replication efforts. Some project replication can occur without financing, especially for cases in which renewable energy technology is the only or the cheapest option. In some cases this may be enough to sustain the critical mass of sales needed to get local supply businesses going, a necessary requisite to growing a market and establishing the technology's commercial credibility sufficiently for financing entities to become interested.

It should be noted that to be successful, this model does not have to be implemented on such a large scale as the Sandia program in Mexico. In the case of the Mexico Renewable Energy Program, a number of activities are being undertaken with multiple partners in several regions, all in parallel, in accordance with the priorities of the program sponsors. Although there are some synergies involved in doing this and larger markets will be created faster as a result, the various activities could also be undertaken separately or in sequence.

Monitoring

Monitoring the results of the program is necessary to evaluate its effectiveness, to learn from it, and to apply the lessons to future work. The program tracks technical performance of the systems installed under the program and sustainability issues such as user training, operation and maintenance provisions, and customer satisfaction. The information is stored in an electronic database which can be used to conduct a wide variety of analyses. Monitoring must be designed into the program from the beginning and sufficient resources allocated to ensure the information collected provides accurate and meaningful information with which to assess and manage the program.

The Mexico Renewable Energy Program in the Context of this Model

The Mexico Renewable Energy Program is founded on high-level intra- and inter-governmental partnerships that were formed in recognition of overlapping goals among different organizations. As mentioned, in the early 1990s, U.S Department of Energy and the Mexico mission of the U.S. Agency for International Development formed a partnership that grew into the Mexico Renewable Energy Program. The program's visibility and broad partnerships led to a Bi-National Agreement, signed by the U.S. and Mexican Secretaries of Energy. In accordance with its terms, Sandia National Laboratories coordinates activities on behalf of the DOE, while the Mexican National Energy Savings Commission (*Comisión Nacional para el Ahorro de Energía* [CONAE]) coordinates activities on behalf of the Mexican Secretariat of Energy. The program activities are implemented through working-level partnerships with a wide variety of project facilitation and implementation organizations in the U.S. and Mexico.

Establishment of Solid, Long-Term Partnerships with Key Organizations

Several different variations on the partnership theme have proven to be quite successful. The State of Chihuahua formed a working-group of 12 governmental, university, and non-government organizations to implement renewable energy projects in the state. Fideicomiso de Riesgo Compartido (FIRCO) is a federal trust for shared risk that works with agricultural development under the Secretariat of Agriculture. It works with the Sandia program through its offices in each state. In the protected-areas management sector, the program was able to work directly with grassroots non-government organizations through their already established partnering arrangements with Conservation International, The Nature Conservancy, and the World Wildlife Fund. Working with ANES tied the program into the existing renewable energy community in Mexico, as did joint work with several universities in Mexico.

- **FIRCO**

The USAID/USAID Mexico Renewable Energy Program partnered with FIRCO's offices in every state that implements projects to increase rural productivity through support for agricultural and small ranch infrastructure enhancement. This has been a key partnership of the program, and Sandia has established contracts with FIRCO in the several Mexican states to make use of renewable energy systems in the course of meeting its agricultural development objectives.

- **Chihuahua Renewable Energy Working Group**

In the State of Chihuahua, 12 governmental, university, and non-governmental organizations work to implement renewable energy projects in the state. Formed under the leadership of Chihuahua's General Directorate of Rural Development (*Dirección General de Desarollo Rural*

[DGDR]), the Chihuahuan Renewable Energy Working Group (*El Grupo de Trabajo de Energía Renovable*) provides a central point of contact and coordination in the state.

- **Protected-Areas Management Partners**

Sandia established contracts with Conservation International, The Nature Conservancy, and the World Wildlife Fund to implement renewable energy projects in managing protected areas and in and near ecologically sensitive regions with these organizations and their local non-government partners in Mexico. This partnering allowed the Sandia team to work directly with credible local non-government development organizations in Mexico and also ensured environmental objectives were being met. Projects are being implemented in several states to provide power for ranger stations, training centers, ecotourism facilities, communications systems, and water pumping.

- **ANES**

Sandia has established a cooperative agreement with ANES, which represents Mexico's larger renewable energy community and serves as Mexico's chapter of the International Solar Energy Society (ISES) (Memorandum 1998). ANES has been involved in the USAID/USDOE Mexico Renewable Energy Program since the beginning, and it has been invaluable in providing guidance to the program and in facilitating the program's acceptance by Mexico's renewable energy community.

- **Other Partnerships in Mexico**

The program has also teamed with a number of universities in Mexico, and, as part of the Bi-National Agreement on energy cooperation, with CONAE, through which bi-national commitments regarding renewable energy are underway. The program is also developing key partnerships with the Federal Energy Commission (*Comisión Federal de Electricidad* [CFE]) and a non-government organization, the Mexican Rural Development Foundation (*Fundación Mexicana de México Desarollo Rural* [FMDR]).

- **Industry Partnerships**

Involving industry is another key requirement to see that the program succeeds, particularly to increase opportunities for U.S. and Mexican business. The Sandia program involves industry as an integral part of the in-country capacity-building process, and more than 45 U.S. and Mexican companies have participated in the program. Many of the program's training workshops involve the installation of actual systems led by industry technicians, and more than a dozen companies have participated in these field training exercises. The Sandia team has worked closely with local suppliers to improve their ability to provide adequate responses to procurement opportunities. As a result of these interactions, several cross-border industrial partnerships have been formed to the benefit of both the U.S. and Mexican businesses. The Sandia program has also worked with U.S. industry members to develop and improve technologies aimed at the Mexican market.

Increased In-Country Capacity To Use Renewable Energy Technologies

The program has trained more than 1,500 people in 90 institutions in 14 Mexican states. Participants were selected carefully for their roles in the program and included decision makers, project managers and engineers, procurement agents, system users, and system suppliers. At least as much informal hands-on training was provided during all stages of implementing the projects. Informal training by its nature is more difficult to measure than formal training, but the true measure of both is whether the primary project-implementation partner organizations are now capable of implementing projects on their own.

The Mexico program has been successful at building within the organizations involved the capacity to make routine use of renewable energy technologies where appropriate in the course of pursuing their development objectives. With the help of U.S. industry, the program has also improved the capacity of local Mexican business to provide quality renewable energy products and services, and in some cases the program has improved the capacity of U.S. industry to do business in Mexico.

Typically, Sandia's program worked with a specific partner, such as a particular state office of FIRCO, through two or three rounds of pilot project implementations, each with a diminishing percentage of hardware cost-share (where cost shares are used).[*] As mentioned previously, a considerable amount of assistance and training (for the implementing organization, the local suppliers, and the user community) is needed from the team initially, but once the partner has been through the process a couple of times, very little assistance is needed from the program team. At that point, the program enters the project replication phase.

The increased capacity to use renewables is evident with several partner organizations. FIRCO is presently defining a program to receive World Bank support for the large-scale implementation of renewable energy technologies in productive-use agricultural applications. In response to the tremendous natural disasters brought on by widespread fires in Mexico in 1998, the Mexican Secretary of Environment, Natural Resources, and Fisheries recently signed an agreement with USAID/Mexico to implement a multi-million dollar program aimed at suppression and control of fires. Based on benefits demonstrated through the Sandia program, this activity will likely include renewable energy components to facilitate radio communications, remote monitoring, and other applications. The Chihuahua state government and other institutions are investigating broad expansion of program activities through financing programs to support both productive use applications and domestic lighting systems.

The protected areas management organizations also are now equipped with the many skills necessary to implement successful renewable energy projects. They have made presentations in public forums and training workshops, demonstrating knowledge about technical, economic, and social issues concerning photovoltaics. Two partner non-government organizations trained

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[*] Note: The Mexican peso crisis hit just as the initial cost-shared pilot projects were getting underway. As a result, FIRCO's project implementation budget was cut to near zero that year, and the Sandia program had to provide larger cost-shares than originally planned to keep the program on track.

through the program have helped communities acquire funds for photovoltaic rural electrification from the respective municipal governments and provided technical assistance to ensure that community systems were of high quality with guarantees and service visits not previously provided to communities in the area.

Another measure of capacity building is how well organizations are able to handle problems on their own, as illustrated by the non-government organization Espacios Naturales, which has responsibility for operation of the 11.4-kW photovoltaic hybrid system that powers the Chajul Biological Research Station in the

Montes Azules Integrated Biosphere Reserve in Chiapas, shown in Figure 5. After accepting responsibility for the system from Conservation International as part of a redefinition of institutional roles with the reserve, Espacios Naturales established a maintenance contract with the system vendor independent of the initial negotiations facilitated by the Sandia team. Rapid response by both Espacios Naturales and the vendor to flooding of the system from Hurricane Mitch demonstrated that the non-government organization is taking full responsibility for the system and that the vendor is honoring the maintenance contract. Other organizations that were already involved in different aspects of renewable energy are building new institutional capacities in conjunction with the Sandia program, including several universities, the national utility, CFE, which is implementing a hybrid photovoltaic/wind/diesel community system in conjunction with a U.S. electric utility, and CONAE.

Figure 5. A hybrid photovoltaic-propane generator system now provides facility power for the Chajul Biological Station in the Montes Azules Integrated Biosphere Reserve in Chiapas.

Through the capacity-building activities of the program, several members of U.S. industry are increasing their ability to do business in Mexico. One company is collaborating with a state government to provide home lighting systems and an innovative hybrid ice making technology. Another is working with Sandia to develop a network of suppliers throughout Mexico and is planning to open a warehouse in Mexico. Other U.S. manufacturers and system integrators have developed partnerships with Mexican businesses who already have strong distribution networks in related fields. Through these partnerships, U.S. companies have found new ways to get their products to the large and growing markets in Mexico.

Summary of Projects in Mexico

Since the beginning of the program, more than 170 pilot renewable energy systems representing more than 100 kW_p have been installed under the program to provide services for more than 14,300 rural Mexicans in nine states, as shown in Figure 6. Figure 7 shows the number of systems installed by application, technology, and capacity, and Figure 8 charts the increasing number of renewable energy systems installed by fiscal year.

More than 40 U.S. and Mexican companies have participated in the program, and several long-term partnerships between U.S. and Mexican industry have been formed from contacts made initially through pilot-project installations. Several interrelated trends have emerged that indicate markets are being established as the visibility of and confidence provided by early installations have increased. In addition, the commitment or buy-in by Mexican partners has increased every year, as shown in Figure 9 as the percentage of costs, and the cost of systems is decreasing over time, indicated by Figure 10, which shows the price for peak watt of installed systems for each fiscal year of the program.

Price reductions are primarily the result of increased competition and improved efficiencies on the part of suppliers, such as reduced needs for post-installation maintenance, and have occurred even as the overall quality of installed systems has improved. All of these factors have contributed to the decreasing costs of systems, but another factor should not be overlooked, which is the size of the system (also shown in Figure 7). From 1997 to 1998, the program-wide cost per watt increased. This can be explained by a couple of factors, most notably the inclusion of new states to the program that have not yet realized savings from increased vendor experience. The other is the installation of smaller systems, where the cost per watt is greater than for a medium to large system.

Sustainability issues, such as system quality and customer satisfaction, are key to establishing growing markets. The quality of the systems installed under the program is assessed through surveys and spot checks of project sites. Because suppliers are required to guarantee the performance of installed systems for a pre-specified period of time, they are motivated to assure quality installations. Preliminary data regarding maintenance actions taken on systems installations through the program illustrate two important points: (1) that relatively few of the installations needed any type of post-installation maintenance; and (2) those systems that required maintenance received it. Another trend indicated by the underlying data shows that in each region maintenance needs decrease over time as markets mature. Continued analysis in this area is underway.

Although maintenance agreements were an underlying factor in the increase in quality of renewable energy systems, the development of minimum technical specifications for water pumping systems contributed to this success. The few maintenance actions that have been required have almost always been related to the wells (e.g., well walls collapsing, or too much algae growing and clogging up a pump), and only about 5 percent of the program's water pumping installations to date have required any maintenance after installation. Obviously, installed projects that work are what lead to good customer satisfaction.

Table 1 shows the results from surveys taken from 20 percent of the water pumping systems installed in Baja California Sur, Chihuahua, Quintana Roo, San Luis Potosi and Sonora. The systems have been installed continuously since 1994. The results indicate that the pilot projects conducted under this program are indeed providing the type of visibility needed to build consumer confidence in the technologies.

The ultimate measure of the program's success is project replication, that is, the establishment of growing and sustainable markets. Market growth occurs both through project replication within development programs implemented by organizations (e.g., FIRCO's agriculture infrastructure enhancement program financed by the World Bank), and through spin-off project replication that occurs completely in the private sector (e.g., sales of photovoltaic water pumping systems to private ranchers). The program is now at a point where the transition from pilot project implementation to project replication is being made. Some preliminary data, indicated in Table 8.2, shows that the early projects are being replicated in regions where the program has had a strong, sustained presence. Continued collection of this type of data is underway. Recent market assessments indicate that the potential for near-term private-sector replication is very large in the sectors where the Sandia program is working.

Figure 6: Geographic distribution of systems installed to date under the program. Shaded areas show states where the program is active, and dots show locations of individual installations.

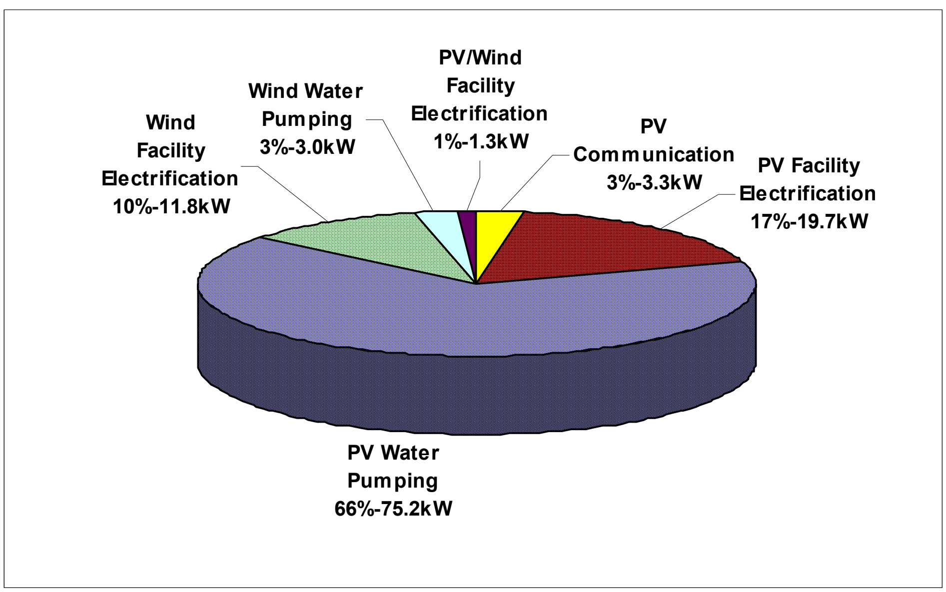

Figure 7. Kilowatt capacity of systems installed through the Mexico Energy program by application and capacity.

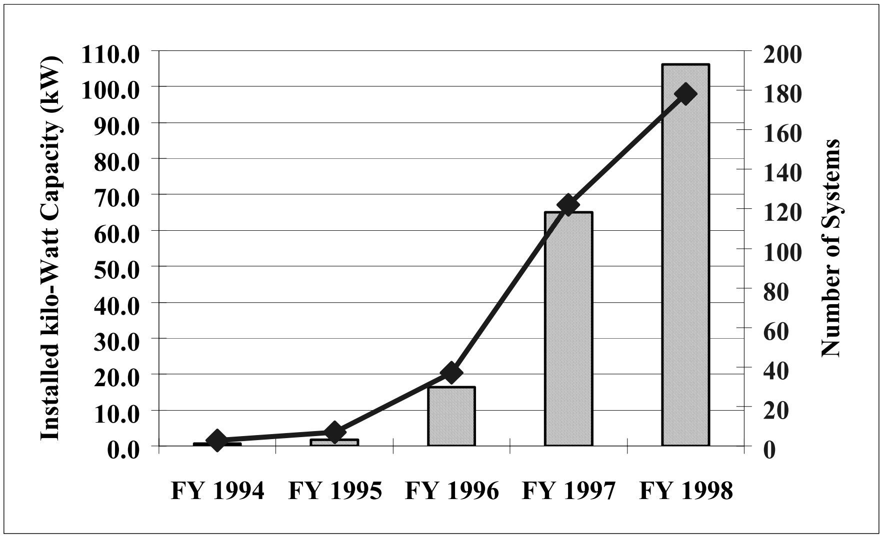

Figure 8. Cumulative installed renewable energy capacity (bar) and number of installed systems (line) by fiscal year (projects installed directly under program, does not include replication).

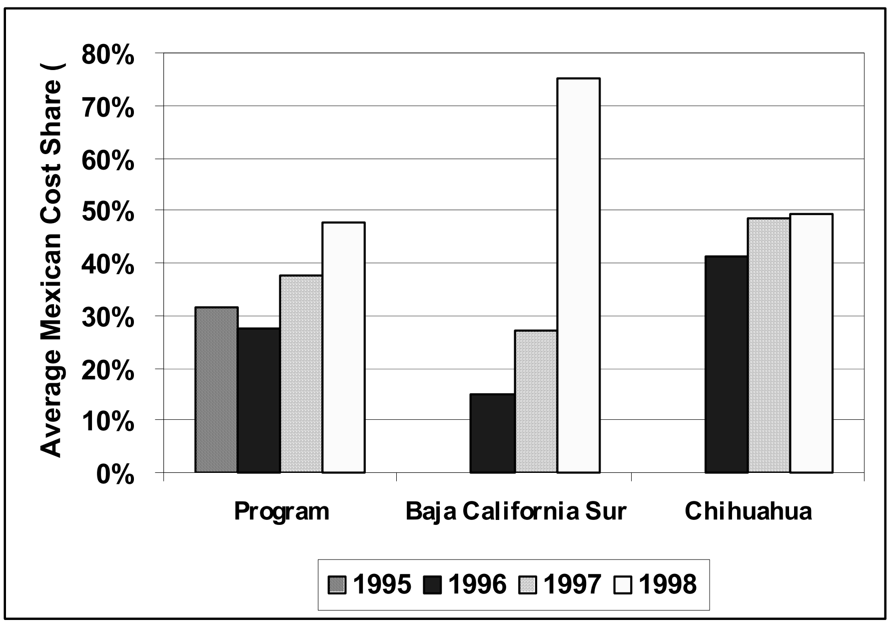

Figure 9. Average Mexican cost-share for photovoltaic water pumping systems hardware.

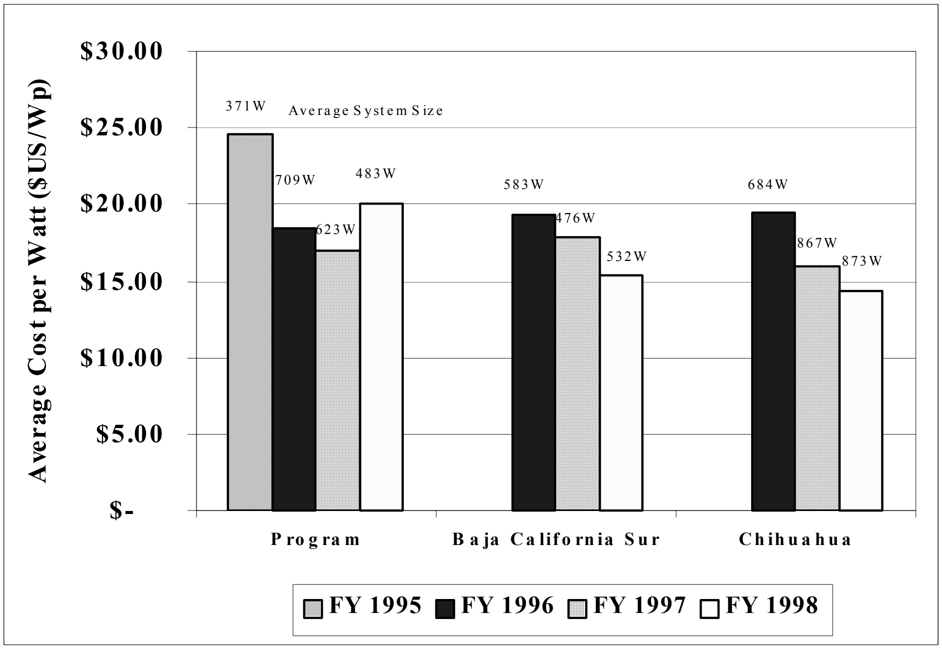

Figure 10: Average price per peak watt of photovoltaic-powered water pumping systems installed under the Mexico Renewable Energy Program.

Table 1: Customer satisfaction with photovoltaic water pumping systems.

	Excellent	Good	Average	Bad
Convenience	77%	23%	0%	0%
Reliability	82%	18%	0%	0%
Performance	95%	5%	0%	0%

Table 2: Examples of spin-off project replication, where program-sponsored installations have led to non-program sponsored installations with the same organizations or in the same regions.

Location	Program Sponsored Installations		Non-Program Sponsored Installations	
	# of systems	KW	# of systems	kW
El Ocote Reserve, Chiapas	10	3.5	141	8
Sonora System Supplier	13	5	35	7
FIRCO Baja California	1	0.1	45	14
Chihuahua System Supplier	4	6.3	76	20

Projections of Carbon Emissions Offset

One of USAID/Mexico's primary objectives, and therefore a primary motivation behind this program, is to reduce carbon dioxide emissions in Mexico (United States Agency for International Development 1998). In comparison with fossil-fuel based energy sources, renewable energy technologies emit only very small amounts of greenhouse gases (Chupka, Howarth and Zoi 1992). Data gathered in the course of program monitoring indicates that the conventional technology most commonly displaced by the photovoltaic water-pumping systems installed as a direct or indirect result of the program is the gasoline-driven motor and pump. Table 8.3 shows the carbon dioxide emissions displaced by the renewable energy systems installed to date under the program.

At this point in the program, the total displacement of carbon dioxide emissions is a small fraction of what is needed to have any meaningful effect on the world's problem as a whole. However, as project replication progresses and the large potential markets for renewable energy technologies are realized, this displacement will grow in proportion to the market. Furthermore, as the program itself is replicated and/or large renewable energy markets are realized elsewhere, this displacement will likewise grow proportionately. The primary objective of the program relating to greenhouse gas emissions will be realized in that the use of renewable energy systems will be established as a practical and commercial—not just theoretical means to offset carbon dioxide and other greenhouse gas emissions.

Table 3: Projected Carbon Dioxide Emissions Displaced by Renewable Energy Systems Installed Under the USAID/USDOE Mexico Renewable Energy Program as of October 1, 1998.

Type of System	Technology Displaced	kW installed capacity	Carbon Dioxide Emissions Displaced (Metric Tons)
PV water pumping[1]	Gasoline engine	70.2 kW	2,922
Wind water pumping[2]	Gasoline engine	3.0 kW	99
PV electrification	Generator	19.7 kW	818
PV communications[1]	Generator	3.3 kW	137
Wind electrification[2]	Generator	10.0 kW	331
Solar still[3]	Propane stove	5 systems	220
Total Carbon Dioxide Emissions Displaced (Metric Tons)			4,527

[1] PV -assumes 6 sun-hours/day, 365 days/year, system life 25 years, 760 metric tons displaced per GWh.

[2] Wind - assumes average annual capacity of 25% at 24 hours per day, 365 days/year, system life 20 years, 755 metric tons displaced per GWh.

[3] Solar stills - assumes 60% efficiency, 6 sun-hours/day, 20 year life, 760 metric tons displaced per GWh.

Lessons Learned During the Program

Implementation of the USAID/USDOE Mexico Renewable Energy Program has provided a wealth of information about what works and, in some cases, what doesn't work in an undertaking such as this. Following are some of the key lessons learned to date or, in the case of the first two, important Photovoltaic Systems Assistance Center philosophies that were reconfirmed.

- **Solid Partnerships Are Essential**

To be successful, a program such as the USAID/USDOE Mexico Renewable Energy Program must work closely with in-country organizations, especially those whose own programmatic objectives are consistent with and can benefit from the use of renewable energy technologies. The program must also work closely with industry, and it must facilitate cross-border business relationships. The need for partnerships also applies to the program team itself, as it is unlikely that any one organization will have in-house all the needed expertise (such as management, business, financing, training, engineering, field experience, development, contracting, environmental, language). And finally, it is important to choose partners carefully, a dictum that cannot be overemphasized. Project success is dependent upon the strength of the partners involved.

- **The Program Must Be Focused To Make the Most of Available Resources**

This goes back to a PVSAC philosophy that it is better to do one thing well than many things poorly. Although it is important to investigate the available options for forming partnerships and tapping into potential markets, it is likely that many more options exist than can be pursued with the resources available. At some point the decision must be made to go with best options at hand with the understanding that other opportunities must be let go, at least for the time being, otherwise program resources will quickly become spread too thin to have much of an effect. Once some concrete successes are realized, they can be built upon in pursuing new opportunities. Furthermore, it is important to focus a sufficient amount of attention on any one geographical location and on a particular application in order to aggregate like markets and create the critical mass of sales needed to get local businesses going and partnerships formed with U.S. industry.

- **Development Issues Must Be Integrated With, and Even Take Precedence Over, Pushing Technology or Environmental Issues**

At the beginning of the program, creating new opportunities for U.S. business was the driving force behind the most of the program's activities. Later, offsetting greenhouse gas emissions became another primary motivator. Although the program has always been focused on economically and socially productive applications of renewable energy, the development agenda per se was not articulated as a goal of the program for some time, although it was recognized by the team that doing development work hand-in-hand with the other program activities was essential for program progress. It was soon recognized by the program team though, that to maximize results in both business and the environment and especially to make them long-lasting and sustainable, the program's activities had to be implemented from a development perspective first. This lesson is relatively well known in the development arena and in some environmental undertakings. However, it is relatively foreign to the technological communities, which are used to focusing on technology itself, and to businesses accustomed to working in more developed economies.

- **Pilot Projects Should Be Used as a Tool, Not An End**

This tenet is extremely important to the USAID/USDOE Mexico Renewable Energy Program. Many renewable energy applications programs have focused on the installations that can be accomplished under the program itself. This limits the vision in terms of establishing growing and sustainable markets. Pilot projects are very beneficial, but their primary value is as tools for training and building the capacity of implementing organizations, business, and the user community. Although the pilot projects can represent significant renewable energy sales in and of themselves, the real market growth is ultimately measured by the project replication that results from the program as a whole.

- **Provisions Should Be Made To Improve the Capacity of Local Business**

The program's success has depended heavily on providing training and technical assistance to local suppliers of renewable energy systems. In the interest of sustainability, the program requires that suppliers guarantee the operation of installed systems and offer terms for follow-on maintenance. Early in the pilot-project implementation phase of the program, difficulties were encountered with local suppliers not being able to meet the bid specifications, deliver qualified product, or provide an acceptable warranty. These difficulties were addressed through training and technical assistance targeted to local suppliers, often provided with help of U.S. industry interested in improving their capacity to do business in Mexico. The improved technical and business capacity of suppliers has led to greater consumer confidence, as well as to less work on the part of the consumer and partner organizations in assuring quality projects. The suppliers are generally very eager to receive the training and assistance.

- **Contracting Mismatches Must Be Addressed Properly**

A key tenet of the program requires that most pilot projects, including hardware procurement, be implemented by the partner organizations to ensure that they establish the in-house capacity to procure renewable energy systems. However, arranging to provide cost-share funds from Sandia to the Mexican partner organizations to facilitate the pilot projects was not a trivial matter. In addition to the usual requirements regarding the use of U.S. federal funds (such as the fact that any equipment paid for by the U.S. government is automatically the property of the U.S. government), the Mexican partner organizations--many of them government agencies themselves--have restrictions on how they can receive and use funds. In particular, they need funds in advance and have different auditing requirements from the U.S.; these are not things the U.S. government is generally prepared to accommodate. Contracting and legal staff must be involved early in the program to negotiate workable cross-border contractual mechanisms. On a related note, to improve the comfort level of the contracting officers responsible for the U.S. federal funds, since the contracts were for payments in advance, a payment/deliverable sequencing system was set up so that only relatively small amounts of money were at risk at any one time. This worked well programmatically and provided protection for the funds.

- **Standardizing System Design Requires an Established Market**

Sandia's experience in the United States suggested that standardizing system design would likewise help expand markets for photovoltaics in Mexico, especially for water-pumping systems. However, it turned out to be a more difficult concept than expected. The market for photovoltaic water pumping is relatively established in the U.S., but in Mexico it still too small relative to the great variety in sizes and types of wells to support standardized system designs, and local industry was not interested in implementing the concept. Since Mexico's market is growing rapidly, at some point it may make sense to reintroduce the concept of standardization, but probably not until the market is mature enough for it to make sense.

- **Theft Protection Must Be Considered in Project Design**

Many of the systems installed through the program are in remote sites where continuous surveillance is impractical or impossible, making the systems susceptible to theft, vandalism, and in some areas, sabotage. As examples, one community water pumping system is located at a well 8 kilometers outside the community, and several radio repeater systems are on remote mountain peaks. Although theft has not been a major problem in the systems installed to date, it has occurred often enough so that insurance is emerging as an issue. Appropriate measures, such as mounting the photovoltaic panels high on towers or concealing them from nearby roadways, should be taken during the design phase of more remote projects to reduce the likelihood of problems.

- **Measuring Replication Requires a Concerted Effort and Significant Resources**

The monitoring process in place for this program is set up to track system installations that are implemented through the program, but it does not yet do an adequate job of tracking replication. Adequate resources must be allocated to ensure monitoring of replication if the true impact of the program is to be known.

- **Multi-Year Planning and Budgeting Are Essential**

A difficulty frequently encountered in government-funded programs is the imposition of a one-year cycle on which to base planning and budgeting. Budgets are uncertain from one year to the next, and often aren't known or change partway into the year. The requirement that, regardless of program priorities and logical schedules, funds must be spent by a certain date or be forfeited can also be hindrance to effective program implementation. The USAID/USDOE Mexico Renewable Energy Program has had the luxury of some multi-year funds with which to plan and implement its activities, as well as some one-year funds. The multi-year planning and budgeting allowed by the multi-year funds have been essential to the program's success. A program of this nature cannot be implemented quickly, and most of the results--as indicated by growing and sustainable markets for renewable energy technologies--will show up near the end of the program and after the program is over.

Future Activities

Work remains to be done before the program is completed. One of the most critical areas is facilitation of financing mechanisms for renewable energy systems. Although this subject was included in the program from the beginning, the Mexican financial crisis that began in late 1994 with the devaluation of the peso and interest rates in excess of 70% effectively derailed the activities. By late 1997, interest rates had settled to around 20% for rural loans, but the Asian and Russian financial crises in 1998 provoked an increase in Mexican interest rates to around 35-40%. The program's initial work in the financing area was in the state of Chihuahua, working with the state government trust fund FIDEAPECH to set up a pilot end-user financing program for renewable energy. This work is still ongoing. Also in Chihuahua, the program has worked with a local company to develop a business plan for a photovoltaic sales and distribution business that includes providing end-user financing through the dealer. The Environmental Enterprises Assistance Fund recently provided a loan to the local company to pursue this strategy, which, if successful, may provide a replicable model for providing end-user financing in other areas. The other financing-related activity the program is pursuing is encouraging the appropriate inclusion of renewable energy systems in Mexican government programs financed by multilateral development bank loans. FIRCO and the Secretariat of Agriculture are proposing to the World Bank and the Global Environmental Facility a financing and grant program in support of renewable energy for agricultural applications. Another area that needs to be addressed is financing for renewable energy projects implemented by non-government organizations.

Increasing the renewable energy industry's involvement in the program is another area needing attention. In particular, more specialized or tailored interactions with individual companies are needed to respond to the particular needs of different businesses. Also, given the estimated size of the markets in Mexico, the program would like to get more U.S. companies interested in Mexico. Care must be taken to ensure that interactions with industry are done on a fair and equitable basis, while at the same time keeping the activities in line with the available program resources.

More program monitoring should be performed. In particular, data on renewable energy business development and spin-off replications (market growth) must be collected and analyzed. Also needed are more in-depth analyses of customer satisfaction and information on the effect the renewable energy systems are having on local economic development via the productive-use applications.

Although the work under this program has so far emphasized photovoltaics, the basic program model is applicable to other technologies and regions. With technical help from the National Renewable Energy Laboratory, some work with small wind systems has been done in Mexico. Solar thermal technologies are now being introduced in the program, and small hydro systems could be incorporated as well. USAID/Mexico is now using parts of the model in its energy efficiency program, and USAID/Brazil has begun to incorporate renewable energy into some of protected-areas management programs using the concepts developed in Mexico.

Summary and Conclusions

The Mexico Renewable Energy Program, led by Sandia National Laboratories for the U.S. Agency for International Development and the U.S. Department of Energy, is making significant progress toward its objectives of enhancing economic and social development, creating new business opportunities, and offsetting greenhouse gas emissions through the establishment of growing and sustainable markets for renewable energy technologies, especially photovoltaics. The model on which the program is based was developed from more than a decade of experience of photovoltaic systems applications work by Sandia's Photovoltaics Systems Assistance Center, combined with several years of experience working with renewable energy in Mexico and other countries. The main facets of the program model are partnerships, in-country capacity-building, technical assistance, pilot project implementation, replication, and monitoring.

Some of the program results to date include the following:

- Increasing numbers of photovoltaic systems are being installed each year.
- Increasing numbers of people are benefiting from productive-use applications of renewable energy.
- Increasing amounts of CO_2 emissions are being offset in Mexico through rural applications of photovoltaic systems.
- Partner organizations in Mexico now have the capacity to make use of photovoltaics in the course of implementing their own development activities.
- Photovoltaic systems are being used on a routine basis as appropriate in large agricultural development programs in Mexico.
- Photovoltaic systems are now eligible to be included for financing under some large-scale agricultural development programs in Mexico.
- Photovoltaic systems have helped improve the management of protected areas in Mexico.

- Local renewable energy suppliers have improved the quality of their installations and their ability to provide customer service.

- U.S. industry has improved its ability to do business in Mexico.

- The price of photovoltaic systems in Mexico has decreased as markets have been aggregated and industry has become more familiar with doing business in Mexico.

Work yet to be done includes the following:

- Continue to facilitate the availability of financing for renewable energy systems.

- Increase the involvement of industry in program activities.

- Expand program monitoring activities to track project replication (market growth) and better understand sustainability issues.

The measure of the program's success will ultimately be how widely projects are replicated beyond the systems that are installed as a direct result of the program. It will likely take a few more years before an accurate estimate of this market growth can be made, but evidence so far suggests that within a few years, total system sales as a direct or indirect result of the program will be significantly greater than the cost of the program itself, and that this number will continue to grow indefinitely after the program is completed.

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